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(54) Title: METHOD FOR INDUCTIVE MEASUREMENT OF A DIMENSION OF AN OBJECT
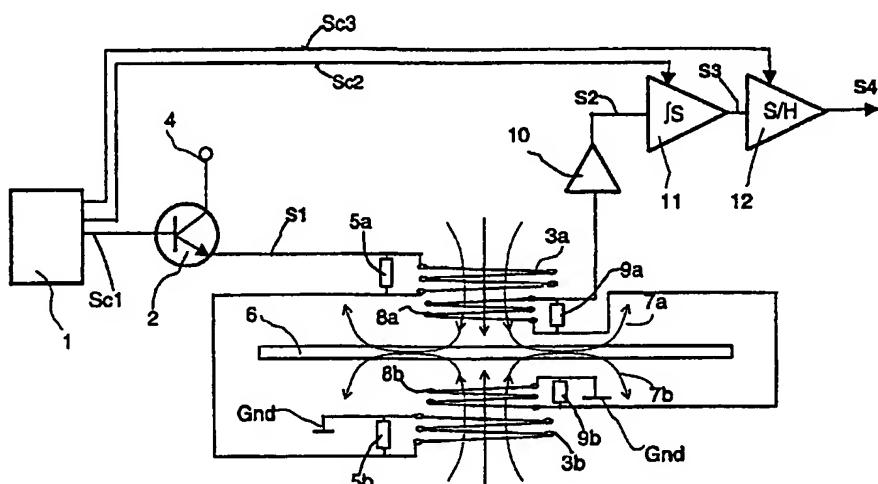
(57) Abstract: A method for non-contact measurement of dimensions such as thickness or diameter and electrical characteristics of an electrically conductive object (6) based on electromagnetic induction and a time-varying magnetic field. A substantially constant current is supplied to at least one transmitter coil (3) such that an electromagnetic field penetrates the object (6). Current to the transmitter coil (3) is cut off and a voltage induced in at least one receiving coil (8) by at least one decaying magnetic field. The voltage in receiving coil (8) is measured from a first time following decay of a magnetic field in the air (T3) until a time when the field has decayed to zero (T4, T5, T6) and the signal is integrated. A value for a physical dimension of the object (6) is calculated from this integral. The method is accurate, undisturbed by surface contamination or object movement, and applicable to different geometric forms including plate, bar or tube.

Method for inductive measurement of a dimension of an object

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TECHNICAL FIELD

The present invention concerns the technical field of the non-contact measurement of a value for first and foremost dimensions such as thickness and diameter of an electrically conducting, substantially non-magnetic object, based on electromagnetic induction. The present invention may also be used in order to measure dimensions as stated above and at the same time as electrical characteristics of the electrically conducting object such as electrical resistivity.

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The present invention may be used during the manufacture of metal products such as plate, or strip, bar or tube where it is desirable to, measure dimensions of those products. It may further be used with measurement of dimensions in connection with pyro-metallurgical processes for production of metals. The present invention may also be used for measurement of dimensions of electrically conductive objects, including non-metallic objects, in another context such as with control of characteristics of metal parts and identification of objects that cannot be seen, such as metal objects in wood in connection with sawing and so on. The present invention may further be applied in applications according to the above where, at the same time, dimensions and electrical characteristics are desired.

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BACKGROUND ART

A known method for non-contact measurement of the thickness of a plate to irradiate it with a radioactive radiation or with x-rays and then measure the absorption of radiation in the plate. This absorption is dependent, amongst others, on thickness of

the plate and constitutes a primary measured value for the
thickness. Variations in the materials composition and coatings
on the surface of the material influence the absorption of
radiation and reduces thereby the accuracy of such equipment.
5   Further, the radiation used in such equipment necessitates
health and safety measures.

It is known to measure the thickness of a strip or plate of an
electrically conducting object with electrical induction
10   methods. One or more transmitting coils produce a time-varying
magnetic field which can penetrate into the electrically
conducting object and there induce a current. These currents in
their turn produce a magnetic field which in its turn induces a
voltage in one or more receiving coils and there the induced
15   voltage is used, after some signal processing, as a measure of
thickness.

Such methods and devices are often based on sinusoidally varying
magnetic fields where changes in amplitude and changes in phase
20   caused by the object are measured. Both of these changes are
influenced by at least three parameters in a measuring system,
object position, electrical resistance of the object and
thickness of the object, and therefore such systems, in their
simplest forms, become fundamentally uncertain. Attempts have
25   been made to solve that problem by introducing measurements at
different frequencies in order, in a sense, to obtain even more
measured parameters, but this has given the result that
interpretation of the signal becomes greatly complicated and the
sufficient measurement accuracy cannot be achieved.
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The above problem has been solved by using a time-varying field
which is characterised by a constant current supplied to a
transmitting coil over a certain time period which is then
suddenly cut off, as described in US 5 059 902. By the use of

this technique an induced signal in a receiving coil is measured during at least three time intervals, one directly after current cut-off, one directly after that and before changes in the magnetic field have had time to penetrate the object of

5   measurement, and lastly during a time interval long after current cut-off when changes in the magnetic field have had time to penetrate the object of measurement. With help of at least these three measured values the thickness of the object can be calculated.

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The above method has been shown to work well in many cases, but each of the three measured values include though a degree of uncertainty. Especially where it concerns the third measured value because speed of the object influences the measured value.

15   Altogether it means that the accuracy of the measured value for thickness is not always as desired.

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A method to measure thickness of a plate is shown in US 5 059 902, with reference to Figure 14, by means of two coils

20   placed on opposites sides of the plate. The plate thickness is measured in that way by measuring the distance between a coil and surface of the plate for each side respectively during a time interval directly following the cut-off of current supplied to the coils. The difference between those distances coil-to-

25   plate surface and the distance between the two coils is thus the thickness of the plate. Under ordinary demands for accuracy this meter works well, but with high demands for accuracy the natural variations in distance between the coils, for example due to temperature, is a considerable problem that reduces the

30   usability of the meter.

One way to measure the dimensions of rod and similar products during manufacture has been described in US applications 09/051333 and 09/051418. The methods have been shown to be

useable for measurement in many production processes such as, for example hot rolling, and even here the methods have shown limitations where the demands for measurement accuracy and stability are very high. These limitations are in a context

5 where measurement accuracy for those types of devices is determined by the accuracy of positioning of coils in the device and the resulting sensitivity for movement in the device.

SUMMARY OF THE INVENTION

10 The object of the present invention is to provide a method and a device for highly accurate inductive measurement of physical dimensions such as diameter or thickness of an electrically conducting object without influence of other varying parameters such as object position and the material parameters of the

15 object. In order to produce highly accurate measurement in practice according to the above it is a precondition that the measured value is directly simply dependent on the dimensions of the object. Further, the measurement is carried out without influence from other material in the proximity of the object,

20 such as water, oil and surface coatings. The geometric dimension is referred to in a particular predetermined direction. Thus, for example the thickness of a flat plate is referred to as a geometric dimension perpendicular to the plane of the plate, and a bars diameter as the geometric dimension perpendicular to the

25 long axis of the bar.

This is achieved according to the present invention by the help of appropriately shaped coils, transmitter coils, supplied with a substantially constant current producing a magnetic field in

30 the object. An important feature of the present invention is that the field is directed so that it has a mean component, the sum of the field, which is generally perpendicular to the desired measurement direction. After a time sufficiently long

enough that the field has stabilised, the current supply to the
coil is cut off.

In a similar way as described in US 5 059 902 the measurement is
5   begun a time after that at which current supply has been cut
off. However, in US 5 059 902 measurement is started directly at
the time that current supply is cut off. In the present
invention, that starting time after which measurement is begun
is determined from the time that it takes for the field outside
10   the object to decay. After the field outside the object has
decayed, the measurement sequence is begun and the integration
of the signal carried out under a time it takes for the field in
the measurement area, the field due to the field in the object
material, to decay. A measurement signal which is an integral
15   based a voltage due to the decay of the field in the object
material is the basis for determining a dimension of the object.
As further described below, that time period after the decay of
the field outside the object may subsequently be divided into
two time intervals from which measurement signals are received
20   which together form the basis for determining a dimension of an
object independent of other parameters.

In the case that thickness of a plate is the geometric dimension
desired, a desirable shape of magnetic field may be brought
25   about according to the invention by means of positioning similar
coils, transmitter coils, one on either side of the plate at the
same distance from the plate and positioned opposite each other
in regard to the magnetic field. When these coils are supplied
with a substantially constant current no magnetic field
30   component is produced in the direction perpendicular to the
plane of the plate, the measurement direction, over the plate.
In the case that the diameter of a bar or tube is the
geometrical dimension that is desired, a desirable shape of the
magnetic field is produced according to the present invention by

means of surrounding the bar/tube with a coil so that the bar/
tube is placed in the centre of the coil.

The minimum time for which current supply should continue before

5   it is cut off depends on the size of object and on the materials
electrical resistivity. The minimum time is proportional to the
square of the dimension and inversely proportional to the
material electrical resistivity and is for example for an
aluminium plate with thickness 2 mm of the order of 50 μ-

10 seconds. The time that should pass from current cut-off till
that time which the integrated measurement should begin should
be as short as possible, but, at the same time include all of
the time lapse for the decay of the field outside the object.
That time is determined substantially by the coils, the

15 transmitter coils, discharge time which is determined by the
inductance of the coils and the electrical components that
surround the coils. Normally that time should be kept shorter
than 1 μ-second. The time that the integrated measurement should
continue for is till substantially all field changes in the

20 measuring area have finished, that is to say, till all
significant magnetic fields have disappeared. That time is of
the same order of magnitude as the minimum time current supply
should continue according to the above.

25 Normally the changes in field are measured by means of the
voltage that is induced in one or more coils, appropriately
positioned. The voltage induced in such a coil is known to be
proportional to dB/dt, the change in magnetic field per unit
time and when the integral for this voltage is taken from the

30 beginning time T_{Start} to the end time T_{Stop} this gives

$$IntegralValue = K * \int_{T_{start}}^{T_{stop}} \frac{dB}{dt} dt = K * (B_{T_{stop}} - B_{T_{stat}}) = K * (0 - B_{T_{start}})$$

where K is the proportionality constant and $B_{Stop} = 0$

where the field is zero at T_{Stop}. This means that the value of the integral will be proportional to the field which, before the current cutoff, existed in the object and as well is a direct measure of the dimension of the object. If the field is

5   substantially constant in the area where the object is, then the value of the integral will be proportional to the dimension of the object. The method according to the present invention also fulfils the goal to give an accurate measurement which is given directly from a measurement value and which is independent of

10   everything apart from dimension.

Measuring coils for measurement of changes in magnetic field are normally placed close to the transmitting coils and symmetrically in relation to them, that being apart from that

15   such placement is necessary for use of the method according to the invention. Measuring coils and transmitting coils may even be the same coils, but used for different functions under different time periods of the measurement. Further, the measurement may be directly measured with suitable techniques

20   and in accordance with the above formula give the intended result for the method.

In the method according to the invention the object may move relative to the preferred position without it causing large

25   measuring errors. With bigger movements or when the most accurate measurements are desired, another embodiment of the invention may be preferred. According to the other embodiment values may be measured, which as well as the summed changes according to the above in the two receiving coils according to

30   the invention, may also be a difference between values from the two receiving coils, and that difference is a measurement of the position of the object.

With the use of the method for measurement of material with high
electrical resistance another preferred embodiment may be used.
According to that, another measurement, as well as those
according to the above, the integrated induced voltage from

5 measuring coils from time T_{Start} to time T_{Stop}, an additional
integrated voltage from time T_{Start} to time T_{Stop} is added after a
fraction of the integrated voltage from T_{Start} to $T1_{Stop}$. That
fraction has the purpose of compensating for the decay of the
field outside the object which decay is not ideally fast and

10 that during the time of that decay a certain outward diffusion
of the field in the material takes place, which diffusion is not
measured. The fraction may be an afterwards empirically
determined and constant fraction or a more complicated,
mathematically determined fraction dependent on both of the

15 measurement values named above.

The present invention may advantageously be used in those cases
when as well as an accurate measurement of a dimension as a
measurement of electrical characteristics, such as electrical

20 resistance and/or magnetic permeability is desired. The
measurement is carried out according to the above with
integration of two induced voltages, the first from time T_{Start} to
time T_{Stop}, the second from time T_{Start} to time $T1_{Stop}$. In the case
where electrical resistance is relatively low it is not

25 necessary for compensation of the measurement of the dimension
and the measurement value for the integrated introduced signal
from T_{Start} to $T1_{Stop}$ may be used for calculation of the electrical
resistance, which is proportional to the square of the integral
value.

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A SHORT DESCRIPTION OF THE DRAWINGS

The present invention will be described in more detail in connection with the enclosed drawings.

5   Figure 1 shows schematically an outline diagram of a measuring device according to the invention.

Figure 2 shows a schematic graph of signal against time which describes time intervals during which measurement takes place according to the invention.

10   Figure 3 shows an embodiment according to the invention for the measurement of an electrical characteristic.

Figure 4 shows another graph of signal against time for measurement of an electrical characteristic according to the invention.

15   Figure 5 shows an embodiment for measurement of a dimension of a bar according to the invention.

Figure 6 shows an embodiment for measurement of two dimensions of an object at the same time according to the invention.

20   DESCRIPTION OF THE PREFERRED EMBODIMENTS

In Figure 1 an outline diagram is shown for measurement of a dimension of thickness of a plate and electrical characteristics of the material of the plate according to the present invention. This comprises a measurement object in the form of a plate 6,

25   transmitter coils 3a and 3b, wherein a small 'a' hereafter refers to one side of the plate and 'b' refers to the other side of the plate. Both of the transmitter coils are supplied during a first measurement period with a substantially constant current from a current source 4 via a transistor 2 which is controlled

30   by a control signal Sc1 from a control circuit 1. During this period of current supply the transistor conducts constant current to the connected transmitter coils 3a, 3b and further to earth at Gnd. Directly after this current supply period the current through the transmitter coils 3a, 3b is cut-off by means

of stopping the current in the transistor. The resistances 5a
and 5b across the transmitter coils 3a, 3b have the function of
discharging the magnetic field that exists in transmitter coils
3a, 3b at current cut-off and carry that function out during a
5   time which is, in a known way, of the order of magnitude of the
coils inductance divided by the resistance.

Transmitter coils 3a and 3b are placed substantially at the same
distance from the plate 6 and are similar in size. In the device
10   illustrated the coils 3a and 3b are arranged such that the
fields that are generated, 7a and 7b, are directed against each
other so that the sum of the field in the centre of the plate 6,
the mean component, does not have a component perpendicular to
the plane of the plate 6. The whole amount of the magnetic field
15   enclosed in the plate, the material field, is therefore
dependent on the thickness of the plate 6.

Relative to the measuring area, that area that is affected by
the field from transmitter coils 3a, 3b as well as the induced
20   phenomenon brought about in the plate 6, two receiving coils 8a
and 8b respectively, are arranged for detection of changes in
the field in the measuring area via the voltage induced in those
receiving coils 8a, 8b. These receiving coils 8a, 8b are of the
same size and placed at the same distance from the plate 6 and
25   connected together in such a way that voltage in both of the
receiving coils 8a, 8b induced by a change in the field is
summed. Across the receiving coils 8a, 8b discharge resistances
9a and 9b are connected which, in the same way as for the
transmitter coils 3a, 3b, determine the discharge time. The
30   voltage induced in the receiving coils 8a, 8b is amplified in an
amplifier 10, from which the time varying signal S2 is formed,
which is thereafter integrated in an integrator 11 during a time
interval controlled by a control signal Sc2 from the control
circuit 1. The signal after completed integration S3 is sent to

a "Sample-and-hold" circuit 12 which takes the signal value
after completed integration in the previous circuit. The signal
value S4 obtained from that circuit is a stable signal value,
relative to time variance, which may be used as a primary
5   measurement value for thickness of the plate 6.

Figure 2 describes the time control and signals of a device in
Figure 1 according to the illustrated invention as a graph of
voltage signal against time. The topmost signal in Figure 2
10 shows the voltage $S1$ across transmitter coils 3a and 3b against
time. Control signal Sc1 to transistor 2 is high from the
time $T1$ to the time $T2$ and switches therefore the transistor so
that current flows through transmitter coils 3a, 3b during that
time. The voltage $S1$ across the transmitter coils 3a, 3b becomes
15 therefore high during that time. From time $T2$ to the time $T6$
the control signal Sc1 is low and the transistor 2 is shut off
so that no current flows through the transmitter coils 3a, 3b
and the voltage $S1$ across the transmitter coils 3a, 3b therefore
becomes 0. After time $T6$ the sequence is repeated. During the
20 time $T1$ to the time $T2$ the magnetic fields 7a, 7b are created
and become of even strength. At time $T2$ the current supply to
the transmitting coils 3a, 3b is suddenly cut-off, so that the
magnetic fields are greatly changed. Receiving coil 8a will
detect that change so that an induced voltage across that coil
25 is proportional to the change in the magnetic field across the
coil, or,

$$S2 = K_c * \frac{dB}{dt}$$

where B is the time-varying magnetic field over the coil, t is
time and K_c is a constant of proportionality dependent on the
30 size and shape of the coil, of the number of turns in the coil
and of the amplification if the amplifier 10. K is thus only

dependent on fixed variables and does not vary with variations
in the object being measured, the plate 6.

As has been described in connection with US 5 059 902 the

5   sequence with a sudden cut-off off current supply to a coil that
is in the proximity of an electrically conducting object is
described by the decay of two conceptual fields, a first decay
of the field outside the object and a second decay of the field
in the material. There is therefore a possibility to distinguish

10   between the decay of each of these fields, by means of the
change in signal that is observed in a measuring coil, which is
evident from the graph of voltage against time for signal $S2$,
second graph from the top. Between the times $T2$ and $T3$ a decay
of the field outside the object is obtained which happens

15   quickly and gives rise to a large change in voltage in the
signal during that time.

The interval begins when the current to the coil generating the
field is cut-off, $T2$, and ends when the field in the coils,

20   principally the transmitter coil, decays at $T3$. According to a
known description, that decay may be determined with the
expression:

$$I = I_0 * e^{-L/R*t}$$

where

25   I is the instantaneous current value through the coil

I_0 is the current through the coil before cut-off

L is the coils inductance

R is the coils discharge resistance (5)

t is the time after current cut-off.

30   When I is of the order of, or less than, 1% of I_0 it can be said
that the field has decayed. This applies if the decay time
according to the above for a receiving coil is chosen
approximately the same or greater than the decay time for the

transmitter coil, which is to be preferred but not a necessary
condition.

The time $T2$ to $T3$ which is the time under which that large

5   change has decayed should be held as short as possible for a
good measurement result and may be influenced by choice of
resistances 5a, 5b, 8a and 8b according to Figure 1. It is
generally so that the higher these resistances are, the faster
signal S2 decays. Normally it is worth making an effort to keep

10   that time shorter than 1 μ-second, which with a coil of typical
diameter of 50 mm and typically 10 turns means that the
resistance typically should be of the order of magnitude of 100
ohm to 1000 ohm.

15   When the signal from the first quickly decaying part which is
related to the field outside the object that has decayed away,
there proceeds slow changes of the magnetic fields which are
related to the decay of the material fields. As the changes here
are slow the voltages that will be induced in the receiving

20   coils 8a, 8b during the time $T3$ to $T4$ are small, which is
evident from the graph for the signal S2. At the time $T4$ the
changes have completely stopped and the signal S2 is then 0.

In the graph of voltage signal against time for the signal S3,

25   the signal after integration in the integration circuit 11
according to Figure 1, the third graph from the top in Figure 2,
the integrated signal is shown. The integrator 11 arranged that
it is zeroed with the help of control signal Sc2 forward till
the time $T3$ and thereafter begins integration of the signal S2.

30   At time $T4$ the change in S2 has ceased, which is why S3 shows a
constant value. The measurement that has been obtained from then
on is a direct measurement of the extent of field that was in
the plate 6 and is in that way a direct measure of the thickness

of plate 6. That measure of the integral at time $T4$ in
consequence is taken with the help of a conventional "Sample-
and-hold" circuit 12 controlled by control signal Sc3. Signal S4
is therein an output signal which is directly proportional to
5   the thickness of the plate.

The embodiment according to Figure 1 and Figure 2 is in no way
limited but is considered to illustrate a method according to
the invention. So also may transmitter and receiving coils be
10   positioned in many ways, so long as the condition that the
fields supplied by the transmitter coils meet each other in the
middle of the plate so that the sum of the fields in the field
direction through the plate, in the plane of measurement,
becomes zero across the plate. Normally this means that the
15   fields meet in the centre of the plate and that the field in the
field direction perpendicular. to the plane of the plate becomes
zero. For the receiving coils it means that they shall be
substantially the same and be positioned so that they detect
field changes in the plate. Receiving coils and transmitting
20   coils may be the same coil and under particular requirements
more than two receiving coils may be used.

The receiving coils may even be substituted by a direct field
measuring instrument, but with the consequence that the signal
25   is not integrated in an integrator but signal values are read
off directly as they occur in time.

The control circuit 1 may be a programmed computer, a built up
or programmed logic circuit or in another known way a built up
30   control circuit. The circuit that cuts off the current supply is
shown in Figure 1 as a transistor 2 but may be any type of
electrical circuit at all which has the ability to suddenly cut-
off current supply to the coil. The circuits on the receiving
side are not limited except to carry out the main task of

obtaining an integrated value of the voltages induced in the
receiving coils between two predetermined times.

In the embodiment according to the above the current has been
5   supplied through the transmitter coils 3a, 3b in a given
direction. What that direction is has no practical significance
for the present invention and that it may even be advantageous
to arrange current supply so that under a period from the time
$T1$ to the time $T2$ according to Figure 2 it has a particular
10 direction in order, subsequently, when the sequence is repeated
after the time $T6$, to supply current in an opposite direction
through the coil. The receiving channel in that case must be
arranged so that it can alternately change the polarity of the
signal produced in order to give a constant value, relative to
15 time variance, for the primary signal.

Another embodiment of the present invention is shown in Figure
3. This embodiment has the aim of solving the same measurement
problem as the embodiment according to Figure 1, but with the
20 difference that this embodiment may be used when the position of
the plate varies in the measuring area, and when the plate has a
high electrical resistance. It may even be used when the plate
is very thick and in that way prevents the movement of time
varying signals from the one side of the plate to the other. It
25 may even be used for the simultaneous measurement of thickness
of a plate and the electrical resistivity of the material of the
plate.

In the embodiment according to Figure 3 the transmitting coils
30 3a, 3b on each side of the plate 6 are supplied by separate but
simultaneously controlled transistors, 2a and 2b respectively.
The transistors 2a, 2b are thereby controlled with the same
control signal, Sc1 from the control unit 1 but supplied with
constant current from independent current supplies, 4a and 4b

respectively. The control signal Sc1 and thereby the sequence of
signals in the coils in this embodiment have the same time
sequence in principle as the time sequence according to Figure
1, but the signals are processed in separate signal channels,

5   beginning with amplifiers 10a and 10b respectively, which in
this case may be one amplifier with differential inputs. The
signals from those amplifiers 10a, 10b proceed to a first part-
channel 11a, 12a and 11b, 12b respectively, arranged for
measurement of thickness in the same way as the channels 11 and

10   12 according to Figure 1 and controlled, in principle, with the
same control signals Sc2 and Sc3, while at the same time another
part-channel is arranged in order to measure the integrated
signal value under a first time interval during the total time
$T3$ to the time $T4$, beginning with $T3$ and ending with the time

15     $T30$, shown in the graph of voltage against time in Figure 4. The
control signal Sc4 from the control unit 1 controls those
integrators, 13a and 13b respectively, in such a way that the
integrators are set to zero up till the time $T3$ according to
Figure 2, there after the integration proceeds to go forward to

20   the time $T30$, after which the integration value is held
constant. At the time $T5$ the integrator are set to zero. The
results from the above integrations are stored with the help of
the "Sample-and-hold" circuits, 14a and 14b respectively.

25   The results from the four signal channels, S5a, S5b, S6a and
S6b, are sent to a common calculation circuit 15. In that
calculation circuit 15 results S5a and S5b are summed, and
become in the same way according to Figure 1 a primary
measurement of the thickness of the plate 6. The difference

30   between both of those signals, S5a-S5b, is further calculated
and becomes a measure of the position of the plate 6 in the
measuring area. That measurement may partly be used to measure
the position of the plate and partly used in order to correct

the primary measurement of thickness of the plate in respect of error depending on deviations in the plate position. In the simplest case this is done partly by subtracting the square of the difference in signal S5a-S5b, from the sum of the signals

5   S5a+S5b according to the expression;

New primary measurement $=(S5a+S5b)-C1*(S5a-S5b)^2$

where $C1$ is thereby a constant which may be calculated or measured through tests with plates of different thickness. This method may also be used to correct for error due to

10   deviations in plate position with the embodiments that have two receiving coils.

In the case that the resistivity of the plate is high or in the case that it is difficult in practice to bring about a

15   sufficiently short decay time for the field outside the object so that the time $T2$ to $T3$ according to Figure 2 becomes relatively long, the signals S6a and S6b may be used in order to correct errors in the primary thickness signals by reason that decay of the material signal had begun at a time sooner than $T3$.

20   The signal values of S6a and S6b respectively may be seen as an expression for the decay at time $T3$ and even times before that and therefore may be used in order to calculate that error. In the simplest case, the decay that takes place before $T3$ is proportional to the decay which took place just after $T3$ and

25   which is measured between the times $T3$ and $T30$ according to Figure 4, because;

Corrected primary signal $S5a=S5a+C2*S6a$

Corrected primary signal $S5b=S5b+C2*S6b$

where $C2$ is a constant which may be determined through

30   calculation or by measurements with plates of known electrical resistance.

In the case where the plate is very thick it may sometimes be
difficult to allow the time interval $T3$ to $T4$ be sufficiently
long enough to allow the field from the object to decay
completely, or so that the signal S2 no longer changes. A long

5 time interval leads to long measurement times so that
measurement cannot be repeated sufficiently frequently. This in
turn may lead to increased disturbance or noise in the
measurement. In such cases the time interval to $T4$ may be
selected before the time that the field from the object has

10 decayed completely and therefor measured signals may be
corrected according to:

Corrected primary signal $S5a = S5a*(1-Fu(S6a/S5a))$

Corrected primary signal $S5b = S5b*(1-Fu(S6b/S5b))$

The function Fu is an unambiguous correction function with a

15 value dependent only on the relation between the values of the
integral between $T3$ and $T30$ and between $T3$ and $T4$ respectively.
The function may be determined by means of carrying out
measurements with plates of known thickness and known electrical
resistivity. Alternatively it may be determined by

20 mathematically solving the problem with known basic differential
equations under the assumption that the field strength before
current cut-off is constant across the plate and that the field
is suddenly cut off.

25 Out of the integrated values between the times $T3$ and $T30$ the
electrical resistivity may also be measured. Thereby
measurements of thickness and electrical resistivity may be
obtained at the same time. In the simplest case the square of
the integrated measured values between $T3$ and $T30$ may be taken

30 as a primary measurement for electrical resistivity of the
material of the object.

In Figure 5 a device according to the present invention is shown
for the measurement of dimensions of a bar, tube or wire. The
object 6 is in this case a bar with cylindrical geometry where
measurement of the diameter is being sought and transmitter coil

5   3 surrounds the object circularly symmetrically. In contrast to
the device according to Figure 1 the simpler geometry in this
case makes it so that measurement may be carried out according
to the invention with only one transmitter coil 3. With the form
of transmitter coil illustrated the condition that the field

10   component in the direction of measurement becomes 0 over the
object is fulfilled. In the same way measurement in this case
may be carried out with receiving coil 8. In general measurement
is carried out in the same way according to Figure 1. In the
same way the integral of the change in field also will be a

15   measure of the field which is stored up in the object under the
period of current supply and the signal S3 and thereby the
signal S4 output from "Sample-and-hold" circuit 12 will be a
direct measure of the bar 6, or its diameter.

20   In Figure 6 a device according to the present invention is shown
for measurement of the dimensions of an object which has limited
extension in all directions. The object 6 may be thought of as a
washer, a coin or similar, for which it is desired to measure a
dimension of size in more than one direction, in this case

25   illustrated, thickness and diameter. The device consists of two
transmitter coils 3a and 3b arranged relative to the object 6
and supplied with current in the same way as in the device
according to Figure 1. Symmetrically in relation to the
transmitter coils 3a, 3b and to the object 6 and arranged in the

30   same way as in Figure 1 are two receiving coils 8a and 8b with a
signal channel connected to an amplifier 10, integrator 11 and
sample-and-hold circuit 12 for generating a measurement signal
S5. In addition there are two further receiving coils 13a and
13b with a signal channel connected with an amplifier 15,

integrator 16 and Sample-and-hold circuit 17, controlled in the same way as the above signal channel, for generating a measurement signal S6. The pairs of receiving coils 8a, 8b as well as 13a, 13b are of different size so that the smaller

5   receiving coil pair 8a, 8b are typically of a size somewhat smaller than the object 6 and the larger receiving coil pair 13a, 13b are typically of a size somewhat larger than the object 6. Both of the measurement signals S5 and S6 are treated in a calculation unit 18, for example a microcomputer, in such a way

10 that dimensions of thickness and diameter are obtained. This is brought about fundamentally by means of using measurement signal S5 which is dependent on both thickness and diameter, but more powerfully dependent on thickness, and measurement signal S6 which is dependent on both thickness and diameter, but more

15 dependent on diameter. In this way, after calculation or measurements with objects of different thickness and diameters, calculation rules for calculation of thickness and diameter derived from measurement signal values of S5 and S6 may be formulated and used in the calculation unit 18.

20

The device according to Figure 6 is in no way limited to the embodiment that is described in connection with the Figures, except that it may easily be realised that the measurement method for dimensions of an object according to the present

25 invention may, where in the cases where more than one dimension is desired, be combined with a plurality of coils and a plurality of measurement channels in order to obtain a plurality of dimensions.

30 The invention according to the previous description has its foremost use for measuring an object that is not relatively large in size. For large objects, such as very thick plate and bar with large diameter, the time taken until changes in the magnetic field have ceased, the time T4 according to Figure 2,

is much too long to be manageable in practice. The long time in those cases means that the measurement cannot be repeated sufficiently often and, because of that, the noise level in the measurement increases which in turn leads in those cases to

5 deteriorated measurement precision. What in those cases would be regarded as a large object also depends on electrical resistivity. For example, an aluminium plate with a thickness of the order of 10 mm may be regarded as thick. In those cases that measurement is carried out on normal as well as thick plates, or

10 correspondingly thick bars, a meter with good functionality may be constructed by using the embodiment described for normal plate thickness, and by means of using the method described in US 5 059 902 to measure distance between coils and surface of the plate. In an alternative embodiment of the invention this is

15 done most simply by changing the control of the integrator Sc2 in Figure 1 or the corresponding integrator(s) in the other Figures, to include the time interval $T2$ to $T3$ according to Figure 2 and the other corresponding figures. In another alternative embodiment of the invention, a thick object may

20 simultaneously have the electrical resistivity of the material of the object measured in combination with the method from US 5 059 902. Likewise, in a further embodiment, an object that is thick in one dimension may simultaneously be measured in another dimension by selecting more than one pair of coils (8a,

25 8b, 13a, 13b), and sizing and placing each pair of coils relative to different dimensions of the object, such as thickness and diameter, that are to be simultaneously measured.

It is within the scope of the claims that an electrically

30 conductive object 6 for which measurements of dimensions such as thickness as well as electrical characteristics may be measured according to the present invention, such an electrically conductive object 6 may be comprised not only of metals such as copper, aluminium and brass etc and alloys thereof, but also of

non-metals, combinations and any other material capable of responding to an induced magnetic field.

Claims

1. A method for non-contact measurement of a physical dimension
of, and an electrical characteristic of, an electrically
conductive object (6) based on electromagnetic induction and a
5   time-varying magnetic field, in which method a substantially
constant current is supplied to at least one transmitter coil
(3) such that an electromagnetic field penetrates the object
(6), subsequently cutting off supply of current to the
transmitter coil (3) and sensing a voltage induced in at least
10   one receiving coil (8) as a result of a decaying magnetic field,
characterised in that said electromagnetic field penetrating
said object (6) is essentially perpendicular to a measurement
direction of said physical dimension and that said method
comprises the steps of
15   -measuring the voltage induced in said at least one receiving
coil (8) from a first time ($T3$) after a decay of a magnetic
field outside said object (6) as a first signal (S)
-calculating a value for said physical dimension of said object
(6) from the first signal (S).
20

2. A method according to claim 1, **characterised** by the step of
-integrating the first signal (S) from the first time ($T3$)
following the decay of the magnetic field outside said object
(6) forward till a point at which the material field has
25   substantially decayed to zero ($T4$, $T5$, $T6$).

3. A method according to claim 1, **characterised** by measuring the
thickness or diameter of said object (6) by integrating the
first signal (S) during the time of the decay of the magnetic
30   field that has penetrated said object (6).

4. A method according to claim 1, **characterised** by a further
step of measuring the electrical resistivity of said object (6)

by simultaneously measuring a voltage induced in said at least
one coil (8) from the first time (T3) after the decay of a
magnetic field outside said object (6) to a second time (T30)
shortly after the first time (T3) and calculating a value for

5   electrical resistivity from that voltage as a second signal
(S6).

5. A method according to claim 4, **characterised** by integrating
the second signal (S6) during the time interval from the first

10   time (T3) after the decay of a magnetic field outside said
object (6) to the second time (T30) shortly after the first time
(T3) which integral is a measure of electrical resistivity of
said object (6).

15   6. A method according to claim 4, **characterised** by calculating a
square of the integral of the second signal (S6) which is
proportional to the electrical resistivity of said object (6).

7. A method according to claim 1, **characterised** by arranging two

20   said transmitter coils (3a, 3b) one on either side of said
object (6) such that magnetic fields induced by each coil meet
substantially in the centre of said object (6) and that the sum
of the magnetic fields penetrating said object (6) is
essentially in a direction perpendicular to the direction of

25   measurement.

8. A method according to claim 7, **characterised** by
-measuring the voltage induced in the at least one receiving
coil (8) from the first time (T3) after the decay of a magnetic

30   field outside said object (6) to the second time (T30) shortly
after the first time (T3)
-calculating a corrected primary signal $S5a = S5a + C2*S6a$ and
$S5b = S5b + C2*S6b$ where $S5a,S5b,S6a,S6b$ are results from four signal

channels, and $C2$ is a constant and by this means correcting
errors in measurement of said physical dimension due to decay of
the material field before the first time ($T3$).

5   9. A method according to claim 7 **characterised** by the steps of:
-adding a fraction of the integral of the signal during the
interval from the first time ($T3$) after the decay of a magnetic
field outside said object (6) until the second time ($T30$) to the
original measured first signal (S).

10

10. A method according to claim 7, **characterised** by the steps
of:
-calculating a corrected primary signal $S5a = S5a*(1-Fu(S6a/S5a))$
and $S5b = S5b*(1-Fu(S6b/S5b))$ where $S5a, S5b, S6a, S6b$ are the results

15   from the four signal channels and Fu is a function dependent
only on the relation between the values of the integral between;
the first time ($T3$) and the second time ($T30$), and between the
first time ($T3$) and a third time to the delay of the material
field ($T4$), as a method to calculate a value for the third time

20   ($T4$) when decay of the material field takes place over a long
time interval.

11. A method according to claim 4, **characterised** by the steps of
-using more than one pair of receiving coils (8a, 8b, 13a, 13b)

25   -selecting the sizes of the coils in relation to different
physical dimensions of the said object (6) such that more than
one physical dimension such as thickness and diameter may be
calculated from signals received in more than one pair of
receiving coils (8a, 8b, 13a, 13b).

30

12. A method according to any of the claims 1-11, **characterised**
in that the said object (6) comprises a metal or metal alloy.

13. A method according to any of the claims 1-11, **characterised** in that the said object (6) comprises a non-metal.

14. A method according to any of the claims 1-11, **characterised**
5 in that the said object (6) comprises a combination of different metals and/or metal alloys.

15. A method according to claim 4, **characterised** by the further step of
10 -calculating a first value from the first signal (S) during a time interval between the time of cutting off current supply ($T2$) and the first time ($T3$) as a distance between a transmitter coil (3) and a surface of the object (6) -calculating from the first value and a distance between the
15 transmitter coils (3a, 3b) said physical dimension of the object (6).

16. A method according to claim 15, **characterised** by the further steps of
20 -using and arranging more than one pair of receiving coils (8a, 8b, 13a, 13b) -selecting the sizes of the coils in relation to different physical dimensions of the said object (6) such that more than one physical dimension such as thickness and diameter may be
25 calculated from signals received in more than one pair of receiving coils (8a, 8b, 13a, 13b).

17. A method according to claim 11, **characterised** by the further step of
30 -calculating a first value from the first signal (S) during a time interval between the time of cutting off current supply ($T2$) and the first time ($T3$) as a distance between a transmitter coil (3) and a surface of the object (6)

-calculating from the first value and a distance between the
transmitter coils (3a, 3b) said physical dimension of the object
(6).

5   18. A method according to claim 17, **characterised** by the further
step of
-calculating a value for the square of the second signal (S6)
from the first time ($T3$) to the second time ($T30$) shortly after
the first time ($T3$) thus providing a value proportional to the
10 electrical resistivity of said object (6).

19. A method for non-contact measurement of a physical dimension
of, and an electrical characteristic of, an electrically
conductive object (6) based on electromagnetic induction and a
15 time-varying magnetic field, in which method a substantially
constant current is supplied to at least one transmitter coil
(3) such that an electromagnetic field penetrates the object
(6), subsequently cutting off supply of current to the
transmitter coil (3) and sensing a voltage induced in at least
20 one receiving coil (8) as a result of a decaying magnetic field,
characterised in that said electromagnetic field penetrating
said object (6) is essentially perpendicular to a measurement
direction of said physical dimension and that said method
comprises the steps of
25 -calculating a first value from a first signal (S) during a time
interval between a time ($T2$) of cutting off current supply, and
a first time ($T3$) after a decay of a magnetic field outside said
object (6), as a distance between a transmitter coil (3) and a
surface of the object (6)
30 -calculating from the first value and a distance between the
transmitter coils (3a, 3b) said physical dimension of said
object (6).

Fig 1

Fig 2

2/3
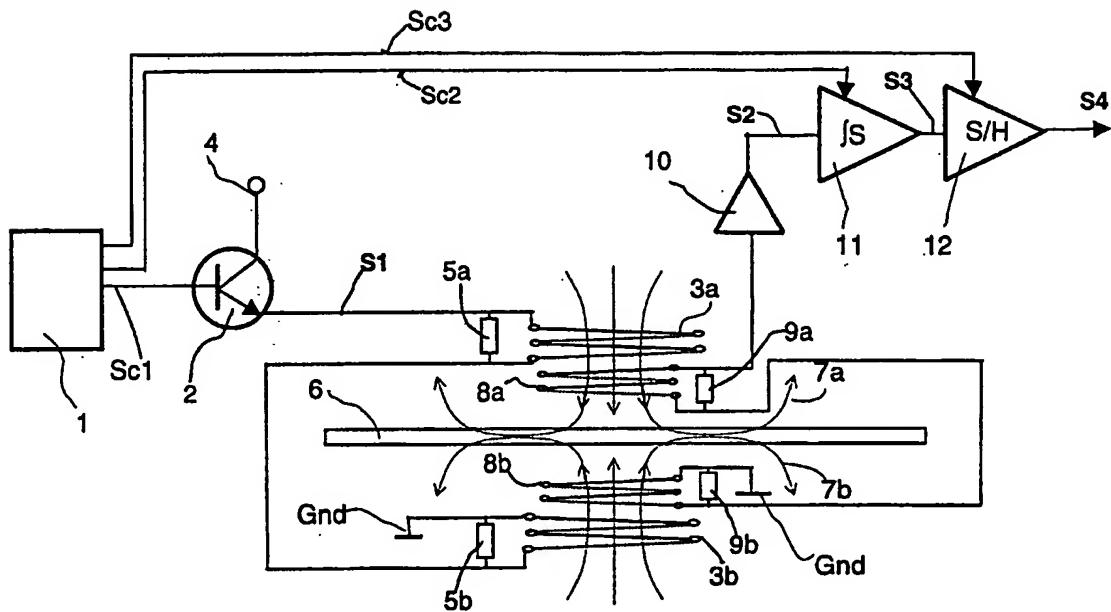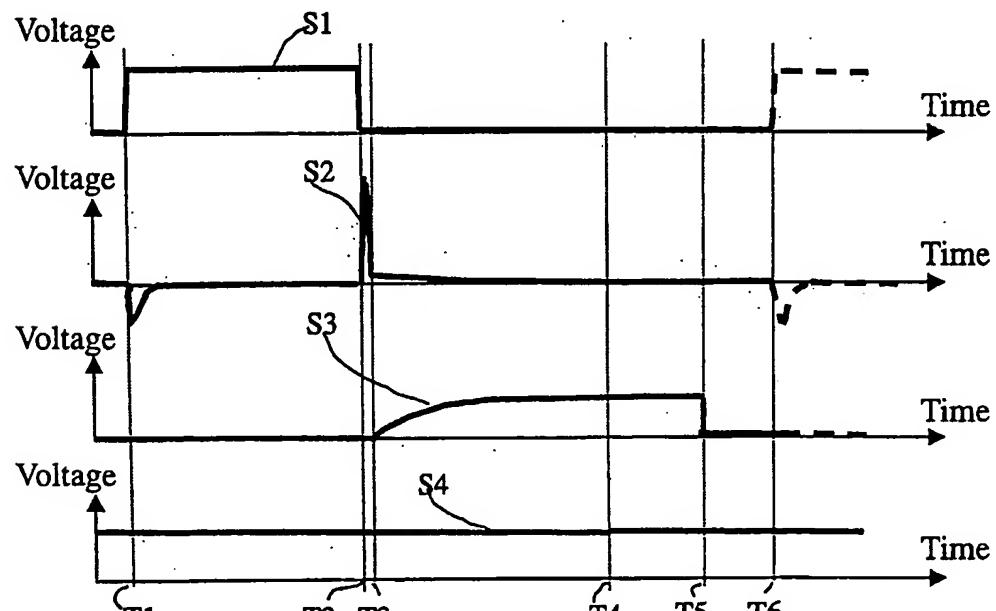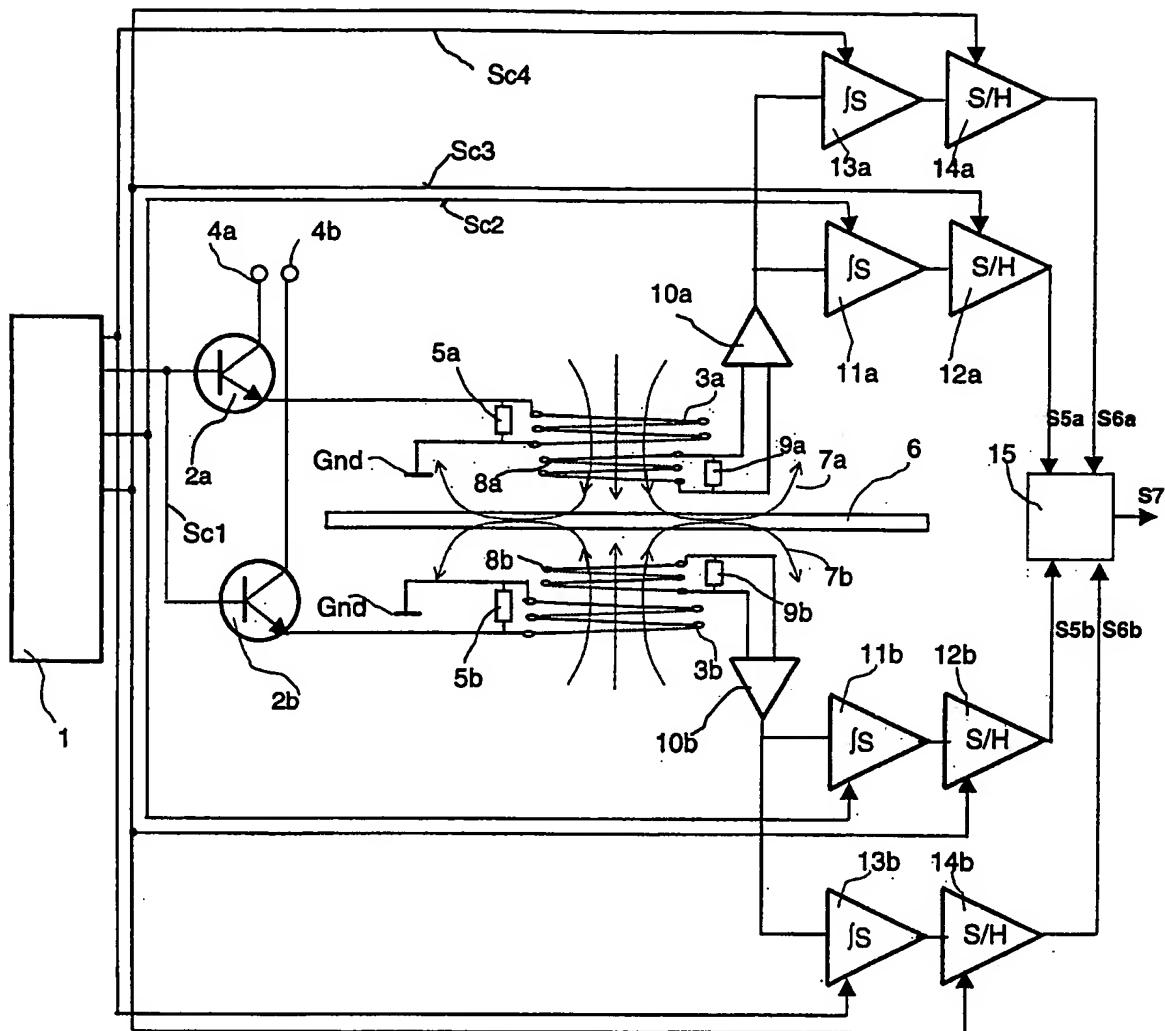
Fig 3
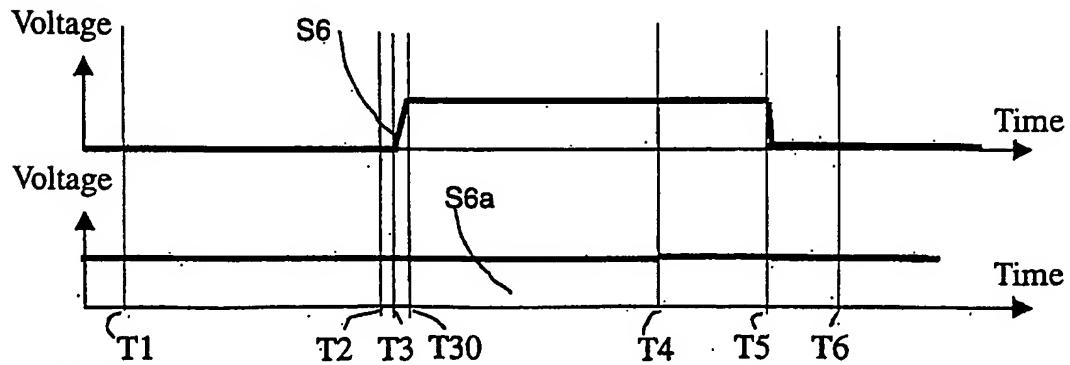
Fig 4
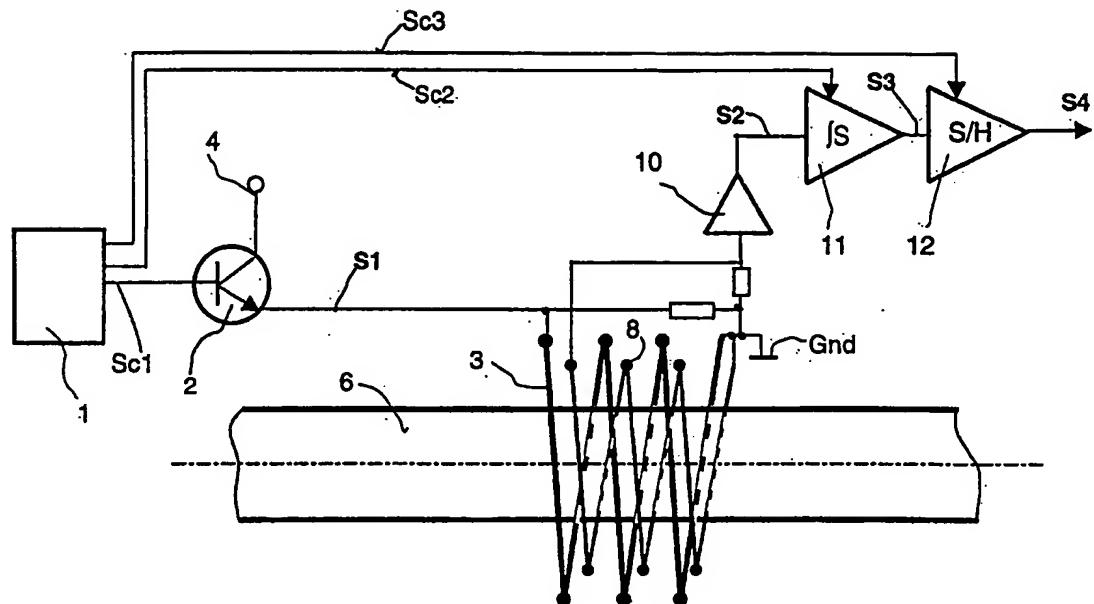
Fig 5
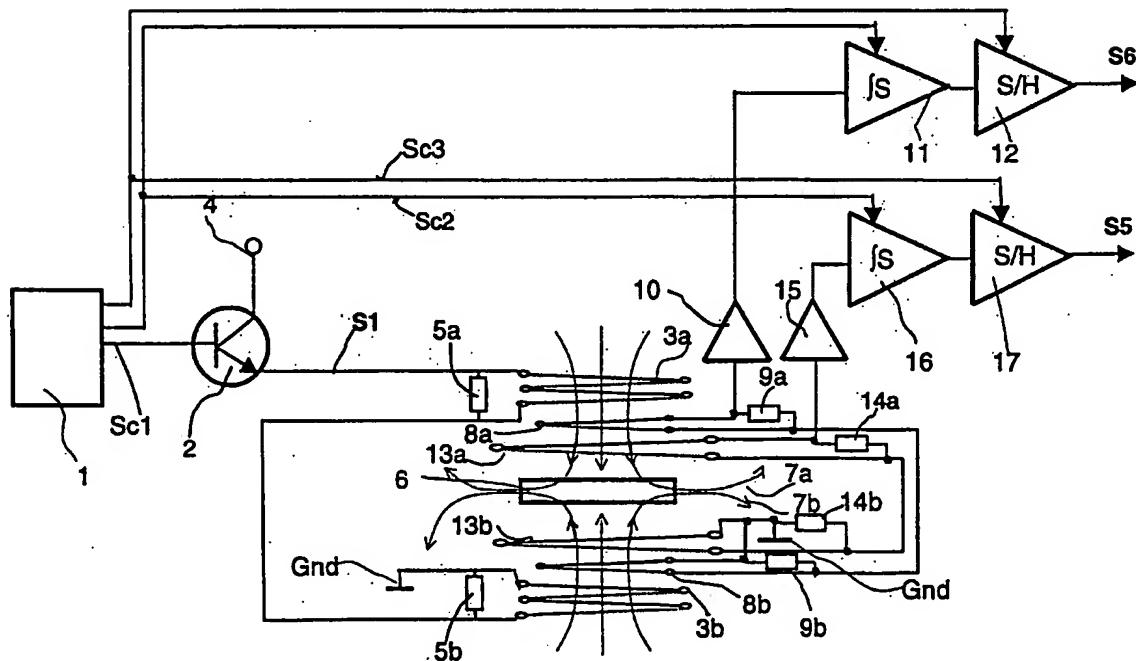
Fig 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 00/01328

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01B 7/00, G01N 27/72, G01N 27/90, G01R 27/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01B, G01N, G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5498958 A (MAI X. TU ET AL), 12 March 1996 (12.03.96), column 4, line 41 - line 43; column 5, line 10 - line 30, figures 11,12	1-19
Y	US 5059902 A (STEN LINDER), 22 October 1991 (22.10.91), abstract	1-19
A	WO 9404996 A1 (DE LA RUE SYSTEMS LIMITED), 3 March 1994 (03.03.94), page 10, line 25 - line 31; page 11, line 6 - line 8	1-19
A	US 5552705 A (G. KELLER), 3 Sept 1996 (03.09.96), column 3, abstract	1-19

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

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21 Sept 2000	1 6 -10- 2000
Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM	Sture Elnäs/MN
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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				EP	0492029	A,B	01/07/92
				SE	0492029	T3	
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				KR	9705129	B	12/04/97
				RU	2072523	C	27/01/97
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				AU	608784	B	18/04/91
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				JP	7078489	B	23/08/95
				SE	451886	B,C	02/11/87
				SE	8604315	D	00/00/00
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